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Progress is reported here in four areas. The work on the relation between CMR and the MLD has suggested that part of the MLD is based upon an analysis of dip information in the stimulus waveform. The work on Mechanisms of modulation detection interference (MDI) has supported the across-channel nature of MDI, and has reinforced the notion that MDI depends upon the average modulation frequency, but not upon the specific modulation pattern or phase. Results suggest that the effect is widely tuned for carrier frequency, and that MDI may not be the most appropriate paradigm for investigating grouping by common modulation, where carrier-specific information must be maintained. The present proposal therefore utilizes paradigms other than MDI. Studies on CMR for suprathreshold signals indicated that large CMR effects are restricted to stimuli presented near detection threshold. Furthermore, CMR information CMR information available at low SLs appears to be coarse, resulting in large DLs for amplitude discrimination, and in poor gap thresholds. Companion experiments on the MLD indicated that the magnitude of suprathreshold masking release was highly similar for the MLD and CMR. In the work on CMR and Auditory Grouping we have investigated the notion that CMR can basically be understood as an auditory grouping

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Overview

Progress is reported here in four areas. The work on the relation between CMR and the MLD has suggested that part of the MLD is based upon an analysis of dip information in the stimulus waveform. The work on Mechanisms of modulation detection interference (MDI) has supported the across-channel nature of MDI, and has reinforced the notion that MDI depends upon the average modulation frequency, but not upon the specific modulation pattern or phase. Results suggest that the effect is widely tuned for carrier frequency, and that MDI may not be the most appropriate paradigm for investigating grouping by common modulation, where carrier-specific information must be maintained. The present proposal therefore utilizes paradigms other than MDI. Studies on CMR for suprathreshold signals indicated that large CMR effects are restricted to stimuli presented near detection threshold. Furthermore, CMR information available at low SLs appears to be coarse, resulting in large DLs for amplitude discrimination, and in poor gap thresholds. Companion experiments on the MLD indicated that the magnitude of suprathreshold masking release was highly similar for the MLD and CMR. In the work on CMR and Auditory Grouping we have investigated the notion that CMR can basically be understood as an auditory grouping process. When a comodulated noise background exists, the individual narrow bands of noise comprising the stimulus may be interpreted as a single auditory source, by virtue of the comodulation among the bands. When a single pure-tone signal is presented in one of the bands, a possible cue for the detection of the signal is the change in the envelope of the on-signal band that does not occur in the other bands. The across-frequency difference may be interpreted as the emergence of an auditory source at the signal frequency that is separate from the on-signal band and its comodulated flanking bands. We have recently used this perspective in an attempt to explain the fact that CMR is often greater when the masker is continuous than when the signal and masker are gated on and off together (Hatch et al., 1995). Because synchronous gating promotes perceptual grouping (Dannenbring and Bregman, 1978; Darwin, 1984; Darwin and Sutherland, 1984) the concurrent gating of both signal and masker may provide information indicating that the signal is simply part of the on-signal masking band. Thus, competing perceptual cues may influence signal detection in gated comodulated noise: the across-frequency difference in envelope resulting from the signal may be taken as evidence that the signal is different from the background, and may therefore aid detection; however, coincident gating of signal and masker may be taken as evidence that the signal is just part of the on-signal masking band, and may therefore inhibit signal detection. Further experiments (see below) are also consistent with interpretation of CMR in terms of auditory grouping. The focus of the new proposed work is therefore to obtain a better understanding of the auditory processes that contribute to auditory grouping by common modulation.

Relation between CMR and the MLD

We have proposed an extension of Durlach's equalization/cancellation (EC) model where, in NoSπ detection, the auditory system compares noise envelopes across frequency. As in monaural CMR, such a comparison would result in threshold improvement when noises are comodulated. We have noted that a difficulty with this hypothesis is that the NoSπ threshold *without* a comodulated flanking band present is already at a signal-to-noise

ratio substantially lower than that for the NoSo threshold with comodulated flanking band present. The difficulty is how an across-frequency envelope cue can contribute to NoSπ detection at signal-to-noise ratios much lower than those associated with monaural CMR. We suggested that one possibility was that an across-frequency comparison (CMR) process might occur following the *output* stage of the MLD EC mechanism. We assumed that independent EC processes occurred at the signal frequency and at the frequency of the comodulated flanking band. As assumed by Durlach, amplitude and/or time jitter result in incomplete cancellation (a noise residue remains which limits signal detection). Because the internal noise is assumed to be multiplicative, the result of the cancellation process [x(t)] will have essentially the same envelope as the left and right inputs to the cancellation mechanism [$n_l(t)$ and $n_r(t)$]. When no signal is present at the signal frequency, the EC noise residue at the signal frequency will therefore be comodulated with the EC noise residue at the flanking frequency. However, when a signal is present, the signal will change the envelope of the EC noise residue at the signal frequency to some extent. Thus, we have proposed that a cue for signal detection might then be the difference in envelope at the output of the EC process for the signal frequency and at the output of the EC process at the flanking frequency. There is one completed project, and one project under way in this area.

a. <u>NoSπ detection with comodulated flanking bands.</u> In one condition, of this experiment, we used only an on-signal No noise band (20-Hz wide), centered on 500 Hz. We obtained NoSo and NoSπ thresholds for this masker. In another condition, four comodulated No flanking bands were added; according to the model, these bands should further improve the NoSπ threshold obtained for the on-signal band alone condition. This, result was obtained. In a further condition where the flanking bands were present only in one ear (that is, the on-signal band was No, and the flanking bands were Nm), so that comodulation information was available, but not presented in such a way that it could be made use of at the output of the EC mechanism. Here, as would be predicted, the addition of the comodulation information did not result in an improvement with respect to NoSπ for the on-signal band alone condition. Present work is underway to assess whether part of this effect may be related to a within-channel interaction between the on-signal band and the flanking bands.

(The following are work in progress on MLD/CMR and auditory grouping)
b. <u>The MLD in low-noise noise.</u> We have argued that a CMR-like process may contribute to NoSπ detection even when no comodulated flanking bands are present. The main assumption is that the auditory system is able to compare the envelope at the input(s) of the cancellation process to the envelope at the output of the cancellation process (Cokely and Hall, 1991). Because the internal noise is assumed to be multiplicative (amplitude and time jitter), the envelope of the inputs of the cancellation process will be comodulated with that of the output when noise alone is present (time jitter is assumed to be very small in relation to the average frequency of the envelope). Furthermore, at the low S/N ratios typical in NoSπ detection, the stimulus (signal + noise) envelopes at the left and right inputs to the cancellation mechanism will also be highly correlated (Cokely and Hall, 1991). However, the S/N ratio will be greater at the output of the cancellation process, and, thus, the signal will have a greater influence on the masker envelope (re its influence at the EC input). This difference in envelope (envelope at the input of the EC device versus envelope at the output of the device) could provide a cue for signal detection under NoSπ conditions, and thus could underlie part of the MLD.

We are examining this hypothesis using "low-noise noise" (Hartmann and Pumplin, 1988). Such noise results in relatively lower NoSo thresholds than obtained in standard noise (Hartmann and Pumplin, 1988). If interpreted in terms of the standard EC mechanism (Durlach, 1963), assuming that the same decision statistics underlie both NoSo and NoSπ thresholds, a similar improvement in NoSπ threshold would be obtained, resulting in no net

effect on the MLD. However, if NoSπ thresholds are based in part upon CMR-like envelope cues, low-noise noise might actually result in no change or even an *increase* in the NoSπ threshold. This is because the envelope-based CMR depends critically upon modulation depth (Grose and Hall, 1989). As "modulation depth" in low-noise noise is low, a masking release based upon envelope cues should likewise be small.

In collaboration with William Hartmann, we are examining MLDs in 10-Hz-wide noise bands, both for standard and low-noise noise. We have examined monaural CMR for the same types of noise, where comodulated flanking bands are present. As expected, CMRs are generally smaller for the low-noise noise stimuli. More interestingly, MLDs are usually also smaller for low-noise noise. In some subjects this is due to the fact that NoSo thresholds are lower in low-noise noise, and NoSπ thresholds are higher in low-noise noise. In other subjects, the NoSo thresholds are lower in low-noise noise than in standard noise, but the NoSπ thresholds are approximately the same in both types of noise. One way of interpreting the latter results is that any benefit that reduced variability provides for NoSπ detection is offset by a reduction in envelope-based cues. We believe that the results obtained so far are consistent with an interpretation that NoSπ detection is partially determined by cues related to noise envelope or that NoSπ detection is partially determined by cues in the dip portions of the masker.

Mechanisms of modulation detection interference (MDI)

Ultimately, our interest in MDI concerns it relation to grouping by common modulation. Our recent experiments have attempted to evaluate the dependence of this effect on across-frequency analysis and upon modulation that is coherent across frequency. There are two completed projects in this area.

a. <u>MDI and frequency proximity</u>. The goal of this study (Mendoza et al., 1995b) was to try to define the relative contributions of across-channel versus within-channel factors. The study examined the detection of sinusoidal AM as a function of the spectral relationship, gating synchrony, and ear of presentation of the target and interfering sounds. Using a 993-Hz target sound, AM detection improved as the frequency of the interferer increased from 1250 to 2188 Hz, and decreased from 788 to 450 Hz. MDI also decreased with continuous interferers. However, MDI was still greatest for interferers most proximal to the target. The effects of frequency proximity and gating asynchrony were also evident using interferers presented to the ear contralateral to the target ear. While a 1250-Hz interferer led to more MDI than a 788-Hz interferer when the interferers were presented to the same ear as a 993-Hz target, no such asymmetry was noted with dichotic stimulation. The main finding of these experiments was that MDI is the result of across-channel, and to only a small extent, within-channel processes.

b. <u>MDI for random versus sinusoidal modulation</u>. The second study (Mendoza et al., 1995a) examined the effect of random versus sinusoidal modulation on MDI. The results of several experiments indicate that the auditory system is sensitive to modulation coherence across spectrally separated noise bands, and that this coherence may promote auditory grouping. If MDI is strongly related to grouping by common modulation, then MDI ought to be affected by whether the modulation pattern for noise carries is comodulated across frequency. We examined MDI for stimuli with random amplitude modulations (RAM), and for sounds with sinusoidal amplitude modulations (SAM), as a function of modulation depth (m) of the interferer. In an experiment comparing comodulated and independent RAM targets and interferers, the amount of interference was *not* related to the modulation coherence of the target and interferer. Elevations in AM threshold increased as a function of m for both conditions similarly. The most interesting results obtained were those that compared MDI for RAM versus SAM stimuli. While no difference was found for AM detection of RAM and SAM, MDI was found to be greater for the RAM stimuli than for the

SAM stimuli. A subsidiary experiment comparing RAM and SAM discrimination indicated that RAM discrimination is more difficult than SAM discrimination. Taken together, these results were consistent with a hypothesis that MDI may be modeled as modulation discrimination at the output of a central channel tuned roughly for modulation rate. Although we believe that coherent modulation is a potentially important auditory grouping factor, we do not believe that the MDI paradigm is particularly sensitive to the processes underlying the processes contributing to such grouping.

CMR for suprathreshold signals

Most CMR studies have investigated auditory processes that enhance signal detection in background noise. One of our goals was to determine the extent to which these auditory processes may also contribute to fine discriminations involving suprathreshold signals. We have completed two separate studies in this area, one examining CMR for temporal gap detection, and the other examining CMR for amplitude discrimination. In each of these studies, data were also collected for the masking-level difference (MLD). The MLD was included so that we could determine whether the suprathreshold masking release occurring for CMR appeared to be similar to that occurring for binaural masking release. Two projects were completed in this area.

a. <u>CMR for gap detection</u>. In the first phase of this study, pure tone *detection* thresholds were obtained in conditions that were associated with CMR, conditions that were associated with the MLD, or conditions that were not associated with masking release (baseline conditions). In the second phase of the study, gap detection was measured with pure-tone markers presented at a given sensation level (SL). Further conditions were run where the gap duration was fixed, and the level of the pure-tone marker was changed adaptively. The study showed two main effects: 1) at a fixed, low SL, gap detection performance was better under non-masking release conditions than masking release conditions; 2) at equal signal SPLs, both MLD and CMR masking release occurred, but the magnitudes of the effects were smaller than obtained for detection threshold.

For fixed gap durations, it was found that CMR for gap detection was often greater for longer than for shorter gap durations. One explanation for this is related to the fact that when the level of the marker is sufficiently high, performance will be near optimal both for masking release and non-masking release conditions. At a high enough signal-to-noise ratio, the masking noise becomes essentially inconsequential. In this respect, masking release effects must be confined to relatively low signal-to-noise ratios. The results indicated that masking release occurs for suprathreshold signals, but the masking release is large only when the precision of temporal resolution called for is relatively coarse. When the temporal resolution must be relatively precise (e.g., 25 ms or better), masking release is likely to be small. Masking release for gap detection was similar in the CMR and MLD paradigms.

b. <u>CMR for amplitude discrimination</u> As in the experiments involving gap detection, the experiment on amplitude discrimination [Hall, 1995 #2904] had an initial phase where pure-tone detection thresholds were obtained, and a second phase where suprathreshold performance was estimated at a number of SLs above masked threshold. Results indicated that, at matched SLs, amplitude discrimination was poorer under conditions of masking release than for baseline conditions, both for the MLD and for CMR. Probably the most interesting outcome of this study was that the overall findings did not agree well with the dip-listening model of Buus, probably the most generally successful model of CMR at this time. In this model, the output of the dip-listening mechanism can be characterized as similar to the input, but at an improved signal-to-noise ratio. That is, the dip portions of the stimulus are given high weighting, thus improving the signal-to-noise ratio. As with the EC model for the MLD, comparable amplitude discrimination performance would be expected

between baseline and masking release conditions at low, matched sensation levels. In other models of CMR, detection depends upon operations concerning the derived envelope rather than the stimulus waveform itself. For example, in the CMR EC model, envelopes at the signal frequency and at a flanking frequency are first extracted, and then the envelope at the signal frequency is subtracted from the envelope at the flanking frequency. When no signal is present, the remainder following subtraction would be minimal, but when a signal is present, the subtraction would leave a material result which would provide a cue for detection. Thus, unlike the dip-listening mechanism, where the output is similar to the input, but at a better signal-to-noise ratio, the output of the CMR EC mechanism can be thought of as the difference between the envelopes of the inputs to the mechanism. Models such as this, where the detection cues in the baseline and masking release conditions are essentially different, are perhaps more compatible with the present data where amplitude discrimination is substantially different between the masking release and baseline conditions, at similar SLs. Over the next year, we will model amplitude discrimination based upon envelope operations versus discrimination based upon waveform operations.

CMR and Auditory Grouping

a. <u>CMR for gated versus continuous backgrounds</u>. Our recent study provided support for the interpretation of CMR gating effects in terms of auditory grouping. We found that CMR was often considerably smaller in gated noise than in continuous noise when few comodulated flanking bands were present, but that when many comodulated flanking bands were present, CMR was more similar between the gated and continuous conditions. This effect occurred because there was a relatively small increase in CMR magnitude with increasing number of continuous noise bands, but a relatively large increase in CMR magnitude with increasing number of gated noise bands. The interpretation of these results was that as more noise bands were added, more auditory channels contributed across-frequency envelope information that could be used to separate the signal from the noise. The cue of synchronous gating became proportionally less effective as the number of channels indicating an across-frequency envelope difference increased.

b. <u>CMR in gated versus continuous broadband comodulated noise</u>. This is the first study that we are aware of that examines gating effects in the CMR paradigm where signal threshold is determined as a function of the bandwidth of a noise masker (Fletcher, 1940). In unmodulated noise, threshold worsens as masker bandwidth is increased, and then remains relatively stable once a critical bandwidth is exceeded (Fletcher, 1940). However, in modulated noise, threshold generally decreases for bandwidths wider than the critical band (Carlyon et al., 1989; Haggard et al., 1990; Hall et al., 1984). This improvement in threshold is attributed to the availability of across-channel differences in envelope that occur when the bandwidth of the masking noise exceeds the auditory filter bandwidth (Hall et al., 1984). The auditory grouping hypothesis suggests several predictions regarding gating effects for the band-widening paradigm. Specifically, CMR is expected to be smaller in gated noise than in continuous noise when the masking bandwidth is relatively narrow, and therefore few auditory channels can contribute across-frequency envelope information. However, as the masking bandwidth is increased to stimulate a relatively large number of quasi-independent auditory channels, the gating effect is expected to diminish. It could even be argued that gating effects should be extremely small or absent when noise bandwidth is relatively wide. According to the perceptual grouping hypothesis, the gating effect arises for multiple bands of comodulated noise primarily because of a difficulty in segregating the pure-tone signal from the on-signal noise band. Segregation is particularly difficult when the pure tone signal and on-signal masker are not only spectrally similar, but also share a common gating pattern. For a relatively broadband masking noise, the masker and pure-tone signal do not share spectral similarity (therefore neither pitch nor timbral similarities).

It would consequently be difficult to argue that common gating of a pure-tone signal and a relatively broadband masker is sufficient to inhibit their segregation.

The signal, generated by a 16-bit Digisound-16 A/D-D/A converter, is a 1000-Hz pure tone, 100 ms or 400 ms in duration including a 50-ms cosine-squared rise/fall time. Four masker bandwidths of 128 Hz (approximately the equivalent rectangular bandwidth (ERB) at the signal frequency), 387 Hz, 921 Hz, and 1505 Hz are used. CMR is determined for the masking bandwidths of 387 Hz, 921 Hz, and 1505 Hz. The first step in this determination is to subtract the modulated noise threshold from the unmodulated noise threshold. It is assumed that when the noise bandwidth is wider than the critical band, the lower threshold in modulated noise is due both to a within-channel effect and to an across channel effect. The within channel effect can be estimated by the difference between the modulated noise threshold and the unmodulated noise threshold in the case where the masker is approximately the ERB (Carlyon et al., 1989). Thus the second step in calculating CMR is to correct for this within-channel effect. That is, the differences between unmodulated and modulated noise thresholds at bandwidths of 387, 921, and 1505 Hz are corrected for the unmodulated/modulated difference for the 128-Hz wide noise masker. The noise bands are centered on the signal frequency and are either unmodulated or have a modulation rate of 10 Hz or 40 Hz. Each masker is either gated simultaneously with the signal or is presented continuously. The pressure spectrum level of each masker is approximately 50 dB SPL.

Results indicate CMR is smaller for the gated noise than the continuous noise for the relatively narrow bandwidth of 387 Hz, but not for the two wider bandwidths. These results provide further support for the idea that simultaneous gating of signal and masker has a disruptive effect on CMR primarily in cases where few frequency channels are available to provide CMR information.

Publications

Hall, J.W., Grose, J.H. and Hatch, D.R. (**1996**). "Effects of masker gating for signal detection in unmodulated and modulated bandlimited noise, " Journal of the Acoustical Society of America. (in press).

Mendoza, L., Hall, J. W., and Grose, J. H. (**1995**). "Within- and across-channel processes in modulation detection interference," Journal of the Acoustical Society of America 97, 3072-3079.

Hatch, D. R., Arne, B.C. and Hall, J.W. (**1995**). "Comodulation masking release (CMR): Effects of gating as a function of number of flanking bands and masker bandwidth," *J. Acoust. Soc. Am.* 97, 3768-3774.

Hall, J. W., and Grose, J. H. (**1995**). "Amplitude discrimination in masking release paradigms," *J. Acoust. Soc. Am.* 98, 847-852.

Mendoza, L., Hall, J. W., and Grose, J. H. (**1995**). "Modulation detection interference (MDI) using random and sinusoidal amplitude modulation," Journal of the Acoustical Society of America 97, 2487-2492.

Grose, J.H. and Hall, J.W. (**1993**). "Gap detection in a narrow band of noise in the presence of a flanking band of noise," Journal of the Acoustical Society of America 93, 1645-1648.

Hall, J.W. and Grose, J.H. (**1992**). "Masking release for gap detection," Phil. Trans. R. Soc. Lond. B 336, 331-337.